THE PRACTICABILITY OF ADOPTING STANDARDS OF QUALITY FOR WATER SUPPLIES*

By Robert B. Morse and Abel Wolman

In spite of the fact that the attempt to establish a so-called standard to serve as a basis for interpreting or classifying the quality of potable waters has met with but little success in the past, endeavors are still being made to standardize the consideration of analytical results so as to eliminate personal judgment as a feature of interpretation. The difficulties besetting these efforts, such as the undetermined significance of the bacterial test made by various methods, the importance of varying chemical content and the evidence of sanitary surroundings, are still present in probably a greater degree than in the past, on account of the development of the science of water bio-chemistry and the added confusion created by the ever changing methods, media, temperatures, and differentiations.

Before establishing a measure of the quality of a potable water, it is necessary to determine by what units such measurements are to be evaluated. In the case of water supplies, the choice of appropriate units becomes difficult, since the question immediately arises as to whether the bacterial count, the B. coli test, the chemical determinations, or the sanitary inspection, should be the sole criterion; or if a combination of these factors, as to what their relative importance should be in any proposed unit of measure. Manifestly a standard in its simplest terms could be predicated upon any single one of the above-mentioned units, if we assume that such a standard would fulfill the requirements of a universal measure of quality. Even then the problem still remains of deciding what unit of bacterial content, for instance, shall be chosen as the basis for comparison.

* Read at the St. Louis Convention, May 15, 1918. Discussions of this paper for publication in a later number of the Journal may be sent to John M. Goodell, Cosmos Club, Washington.

A unit of measure must be founded upon the existence of an absolute uniformity of condition and of material which can be made to serve as the immutable basis for future comparative readings. The unit of length, for example, is that distance between the ends of a bar of definite material, in a definite place, measured and corrected for predetermined conditions of atmospheric pressure and temperature. Such a unit immediately establishes a precise standard by means of which further measurements of length under all conditions may be carried out. The search for a "quality standard" for water should be first directed, therefore, towards determining whether there are available any definite units in sanitary science which can serve as the basis for a standard.

If the water analysts have agreed upon well-defined methods of water analysis, then the evaluation of a standard would be at least possible, if not valuable, for interpretation. In order to learn whether any degree of uniformity existed in the laboratory examination of water supplies, a questionnaire was submitted to 33 state department of health laboratories in the United States. Thirty-two answers were received and sufficiently detailed information was obtained to warrant the conclusions later to be discussed. With these data at hand, the practicability, at the present time, of formulating a standard of quality for water, in the light of present day analytical practice, may be discussed with more precision.

Total bacterial count. The total number of bacteria in a stated quantity of water has been used frequently in establishing a maximum allowable pollution in potable waters. One of the more recent of these is the requirement of the United States Treasury Department that water supplied to common carriers should contain no more than 100 bacteria per cubic centimeter (37°—24 hours—agar). The creation of such standards presupposes a unanimity of opinion as to the significance and importance of particular bacterial counts obtained by definite procedures, over others found by any other methods. Such an agreement would be reflected, of course, in the routine procedures of laboratories. The data in table 1 disclose, however, a disconcertingly wide difference, rather than agreement, of attitude toward the various methods. If official water analysts differ in their choice of the method of making total counts, it is reasonable to conclude that their disagreement would be even greater in a choice of a "standard" total count. Since the relative significance, for instance, of the total number of bacteria on a plain

TABLE 1

Method of obtaining total bacterial count in laboratories of various state departments of health

NAME OF STATE	20°C.				37°C.				
	Gelatine		Agar		Gelatine	Agar		Lit. Lact. Agar	
	48 hrs.	96 hrs.	48 hrs.	96 hr .	48 hrs.	24 hrs.	48 hrs.	24 hrs.	48 hrs.
California						+			
Connecticut	+					+			
District of Columbia			+(a)						
Florida							+		
Georgia						+			
Illinois	+					+			
Indiana						+			
Iowa			+					+	
Kansas	+					+			
Kentucky						+			
Maine	+					+			
Maryland			+			+			
Massachusetts				+				+	
Michigan						+			
Minnesota				+					
Missouri						+	+		
Montana						+			
New Jersey			+			+		+	
New York					+	+(b)			
North Carolina	+							+	
Ohio			+			+			
Oklahoma						+			
Pennsylvania							+		
Rhode Island			+					+	
South Carolina						+	+		
South Dakota							+		
Vermont						+			
Virginia						+			
West Virginia							+		
Wisconsin		+(c)							+
Wyoming	+						+		

NOTE: Data in above table obtained by letter in 1917 from officials of various state departments of health.

(a)—25°C.

(b)—Infrequent.

(c)—15° to 20°C.

agar plate at 37°C., as compared with the count on a gelatine plate at 20°C., is still a moot question, it is clear that more confusion in interpretation will result when several additional different combinations of media, temperatures, and periods of incubation are to be considered.

It is also of striking interest to note that, in spite of the fact that the 37°C. agar count at twenty-four hours incubation has been for several years an official standard procedure of at least two organizations (American Public Health Association and United States Treasury Department), only 19, or approximately 60 per cent, of the laboratories in question have seen fit to use this exact procedure as a routine measure. The percentage is undoubtedly higher than that which would represent the individual opinions of the analysts in these laboratories, in view of the fact that some of them have adopted the aforementioned methods on account of their official stamp rather than as a result of the conviction that they are superior to others. This conclusion is borne out by the fact that it has been by no means firmly established that the bacterial count, obtained as outlined by the Federal requirements, serves as the best index to the quality of a drinking water. In the light of the data illustrating the wide discrepancy in the method of obtaining the bacterial count, it would appear that effort should be directed towards further study of individual types of bacteria and their relative significance rather than towards an attempt to predicate a standard upon such an elusive and variable factor as the general bacterial count.

B. coli. An index to sewage pollution in potable waters is an excellent asset in determining the safety of a supply if it "indicates." Some years ago, perhaps, the presence of B. coli in small quantities of water was considered sufficient evidence upon which to condemn the supply. He certainly would be venturesome who would issue a manifesto today as to the allowable frequency of B. coli in a safe water. He would indeed be skillful who can gather sufficiently consistent data out of the present chaotic conception of the significance of B. coli, and of how to obtain it, to be able to establish even a fairly elastic measure of quality.

Table 2 illustrates, for instance, that the use of a medium for testing even the elementary phenomenon of gas formation is still open to question, while the significance of gas formation itself is disputed by authorities. Considerable evidence has supported previously the use of lactose bile, but the wind has apparently shifted in recent

TABLE 2

Method of making presumptive tests for B. coli in laboratories of various state departments of health

NAME OF STATE	MEDIUM USED		PERIOD OF INCUBATION	
	Lactose broth	Lactose bile	48 hours	72 hours
California	+		+	
Connecticut	+		+	
District of Columbia		+	+	
Florida	+		+	
Georgia	+		+	
Illinois	+		+	
Indiana	+		+	
Iowa	+		+	
Kansas	+	+	+	
Kentucky	+		+	
Maine		+	+	
Maryland	+		+	
Massachusetts	+		+	
Michigan	+		+	
Minnesota	+		+	
Missouri	+		+	
Montana	+		+	
New Hampshire		+	+ (c)	
New Jersey	+	+ (a)	+	
North Carolina		+	+	
North Dakota				
Ohio	+		+	
Oklahoma	+		+	
Rhode Island	+		+	
South Carolina		+		+
South Dakota	+		+	
Tennessee				
Vermont	(b)		+	
Virginia		+	+	
W. Virginia	+		+	

NOTE: See note in table 1.
(a) Infrequent.
(b) Lactose neutral red.
(c) Thirty-six hours.

years and the balance now rests upon the importance of lactose broth as a better medium for an initial B. coli test. Each day brings forth another experimental factor to make the confusion greater as to the significance of lactose fracture.

The data given in table 2 show a close agreement in the laboratories as to the necessary period of incubation in the B. coli presumptive test. In the face of the almost universal choice of a forty-eight hour period, it is found in the Maryland State Department of Health laboratory that about 25 per cent of all typical B. coli isolations are obtained from those tubes which show gas only after seventy-two hours incubation. It is somewhat doubtful, with the evidence shown in table 3, whether even the apparently settled question of period of incubation is not still debatable.

TABLE 3

The effect of an increased period of incubation in the presumptive test upon the possible number of confirmatory tests

Total number of tubes incubated and giving gas = 495

GAS FORMATION AT END OF	NUMBER TUBES SHOWING GAS		PER CENT TUBES SHOWING GAS		NUMBER CONFIRMED		PER CENT OF TOTAL TUBES CONFIRMED	PER CENT OF TOTAL SAMPLES CONFIRMED
	Total	Additional	Total	Additional	Total	Additional		
hours								
24	18	18	3.6	3.6	17	17	6.2	3.4
48	263	245	53.1	49.5	197	180	66.0	36.0
72	448	185	90.5	37.4	264	67	24.6	13.4
96	495	47	100.0	9.5	273	9	3.3	1.8

NOTE: Data obtained from routine analytical determinations in laboratory of Maryland State Department of Health during a period in 1917. Presumptive tests in lactose broth. Confirmatory tests consisted of Endo, secondary lactose broth, and agar slant.

The significance of the presumptive test has been complicated recently still further by the work of Hasseltine[1] who has pointed out the importance of such details as the sterilization of media, owing to the possible breaking down of the sugars in autoclave sterilization into monosaccharides, with consequent gas production by types other than B. coli. It is clear, therefore, that the various features of choice of media, period of incubation, sterilization, and of reaction must be considered of far more importance in any future standardization than has been the case in the past.

If we subscribe, in addition, to the assumption that gas formation is not a true index of the presence of B. coli, then a unified interpretation of quality approaches still more closely the mythical pot of

[1] Hasseltine, U. S. Public Health Service Reports, Vol. 32, No. 45, November 9, 1917.

TABLE 4

Methods used in various state department of health laboratories in confirming the presence of B. coli

NAME OF STATE	MEDIA USED																REMARKS
	Lactose broth	Lactose bile	Endo	Litmus lactose agar	Second lactose broth	Gelatine	Litmus milk	Dextrose broth	Indol test	Nitrate test	Dulcite	Gram stain	Agar slant	Motility	Russells' medium	Test for anaerobes	
California	+			+	+												
Connecticut	+		+		+								+				
District of Columbia		+	+														
Florida	+		+														
Georgia	+			+	+												
Illinois	+		+		+												Presumptive test in most instances
Indiana	+		+		+												
Iowa	+		+	+													Eosine-methylene-agar for experimental work
Kansas	+	+	+		+												Add. det. infrequently
Kentucky	+		+		+												
Maine		+		+	+												
Maryland	+		+		+												
Massachusetts	+			+													
Michigan	+			+	+												
Minnesota	+			+	+							+	+	+			
Missouri	+			+													
Montana	+			+	+	+											

New Hampshire		+															
New Jersey	+		+														Usually
New Jersey		+	+		+	+	+	+			+						Infrequently
New York			+	+	+	+	+		+	+							
North Carolina		+	+														
Ohio	+			+	+												
Oklahoma	+			+													
Pennsylvania				+				+	+								
Rhode Island	+			+													
South Carolina		+															
South Dakota	+			+	+	(Bile)						+		+	+		
Vermont				+													Also lactose neutral red
Virginia		+	+		+	(Bile)											
West Virginia	+																Public supplies
West Virginia	+			+	+										+	+	Private supplies
Wisconsin				+													
Wyoming	+		+														Also bile salt agar

NOTE: See note in table 1.

gold at the end of the "standard" rainbow. In fact, when subjected to the various discriminatory tests now available to the analyst, the much maligned bacillus coli seems to emulate the historic chameleon in all its possible forms. Table 4 indicates only slightly the variations in methods of confirming the presence of the B. coli in use in various state laboratories. This ubiquitous bacterium now poses either as the "survival of the fittest," after running the gamut of several sugar fermentations, gelatine, indol, nitrate, milk, and hydrogen-ion concentration determinations, at the hands of the city health commissioner, anxious to divert criticism from a water supply by seizing upon the "fecal type" of B. coli as his measure of quality; or else it assumes the shape of the simple initial lactose fractor serving as the proud exhibit of the fortunate filtration plant operator blessed with the excellent results of operation.

What shall the standard test for B. coli include, if a mere difference in the proportions of fuchsin and of sulphite in two Endo media, results[1] in the one showing typical colonies in 75 per cent of the tubes in which the B. coli is present, while the other shows the same colonies in only 14 per cent? Shall the lactose broth, to be used in the presumptive test, contain 0.5 or 1.0 per cent lactose,[2] if the latter is detrimental to the successful isolation of B. coli? Certainly, we dodge the issue somewhat if our standard vaguely demands, for example, that the "colon bacillus should be absent in 100 cc." Why the colon bacillus? How shall we know it? How often can it occur in 100 cc. without condemning the supply? These are questions which "standards" skillfully avoid answering.

In 1907, Phelps[3] discussed a method of estimating the numbers of B. coli from fermentation tube results. His system of numerical interpretation has served, until recently, as the basis of practically all quantitative estimates of B. coli in various waters. A misconception of the method proposed at that time has been responsible in a degree for the eternal cry for standardization. The realization of the fact[3] that "the method is obviously of no value for single tests and finds its most useful application in routine studies in water purification and sewage treatment extending over long periods of time" would tend to emphasize the utility, but uncertainty, of

[2] Levine, Notes on the Presumptive Test for B. coli. Engineering Exp. Sta., Ames, Iowa, 1917.

[3] Phelps, Method for Calculating Numbers of B. coli. *Jour. A. P. H. A.*, September 30. 1907.

fermentation tube results as usually obtained, as a basis for numerical interpretation. Granting the value of establishing a maximum allowable pollution of "x" B. coli per 100 cc., we are confronted still with the difficulty of estimating such numbers from the data afforded by our present bacteriological methods.

Greenwood and Yule[4] have indicated this difficulty in a remarkably clear manner, in the following passage:

> The fact that a given volume of water tested contains no bacilli or none which will grow, does not prove that the source of supply is sterile, the point is merely that the greater the volume tested with negative results the smaller is likely to be the population of organisms existing in the supply; none of the writers has attempted to provide a scale of bacterial densities corresponding to the increase of the minimum quantity of water found sterile on examination (not strictly true*). We think, indeed, that the tenor of the passages cited (referring to various standards*) creates a presumption that the authors' criterion really is that sources *shown by other methods or found from practical experience* to be safe or to be unsafe have *usually* been found to give sterile readings when samples of the assigned size have been tested. This would explain, for instance, the lower standard adopted in the case of moorland waters. This is undoubtedly a reasonable attitude of mind enough, but it is necessary to remark that the process is not wholly satisfactory, since two observers both testing the same source on, say, the basis of a sample of 100 cc. might obtain the one a positive, the other a negative result, so that one would reject, and the other pass the supply. Further, no criterion is provided of the increase in accuracy of prediction attained when two, three or more samples of 100 cc. all give sterile readings.
>
> * Notations by Morse and Wolman.

If the so-called B. coli index is to serve as the measure of the quality of a water supply, assuming that the technique of B. coli determination has been satisfactorily settled, the necessity still remains of determining the method of obtaining the index. The number of methods now available for determining the B. coli index introduces at once further complications. Shall a proposed standard embody the procedures of Phelps,[3] Greenwood and Yule,[4] McCrady,[5] Stein[6] or Wells?[7] The method of Phelps enjoys con-

[4] Greenwood and Yule, On the Statistical Interpretation of Some Bacteriological Methods Employed in Water Analysis. *Jour. of Hygiene,* July, 1917.

[5] McCrady, The Numerical Interpretation of Fermentation Tube Results. *Jour. of Infectious Diseases,* July, 1915, Vol. 17, No. 1.

[6] Stein, Making the B. Coli Test Tell More. *Eng. News. Rec.,* May 24, 1917.

[7] Wells, The Geometrical Mean as B. Coli Index. *Science,* January, 1917.

siderable popularity because of ease of application. Unfortunately agreement as to method has not always resulted in accuracy of application. In spite of the limitations discussed by Phelps, B. coli indices are calculated indiscriminately with few or many analytical results at hand. The fact that there may be three or three hundred results has generally no effect upon the use of the B. coli index in the hands of sanitary engineer, bacteriologist, or filtration plant operator. Twenty per cent positive in 1 cc. is used with the same significance whether as a result of five or five hundred samples. The further injunction that both positive and negative results should be obtained on limiting dilutions of water is treated, in a number of cases, with the same disregard for accuracy. One of the well-known filtration plants reports, for instance, a B. coli index of 0.7066 (number per cubic centimeter), from the following results: 100 per cent positive in 10 cc. and 67.4 per cent positive in 1 cc. No tests were made on 0.1 cc. samples, the note blithely stating that such tests were assumed to be zero. That such an abuse of the Phelps' method is not a rare occurrence is evidenced by the frequent repetition of such findings as the above. Standardization of quality would hardly obviate such statistical juggling as produced by another of the largest filtration plants in the United States, which reports a B. coli content of the filter effluent of 0.44 per cubic centimeter, based upon 77 per cent and 40 per cent positives in 10 and 1 cc. dilutions respectively. Here again the 0.1 cc. samples are naively placed in the negative column on the basis of a total of 13 tests, as against 314 in both 10 and 1 cc. dilutions. Aside from justifying the theoretical basis of the Phelps method, the further establishment of allowable numbers of B. coli in a water supply would demand far more restrictions upon its use and evaluation than are observed apparently by a number of water supply workers at the present writing.

Variations in the numerical interpretation of fermentation tube results have engaged recently the attention of analysts, with resulting surprising discrepancies in data obtained by different methods. These findings illustrate only too well the weakness of establishing standards upon such meager bases, as, for instance, the "absence of B. coli in 100 cc." Observation that 50 per cent of 0.1 cc. samples have given a positive test may be interpreted as indicating a source of supply containing a B. coli content differing by over 100 per cent, depending upon the method of quantitative determination employed.

Both McCrady and Stein would assign to the above result a bacterial content of 700 per 100 cc., Greenwood and Yule a value of 690, and Phelps a value of 500, while Wells would assume the probable existence of only 317. Even a result of +100, +10, −1, and −0.1 assumes a dual rôle depending upon the judgment of the interpreter, for the adherent to the "reciprocal of highest positive dilution" method would find a B. coli content of 10 per 100 cc., while advocates of several of the later procedures would support the probable existence of 23 per 100 cc. A mere difference of over 100 per cent! Table 5 is of interest in illustrating the varying possibilities of interpretation of the quality of a filter effluent, with no variation whatever in the fermentation tube results obtained under actual operating conditions.

TABLE 5

Influence of method of obtaining the number of B. coli from fermentation tube results upon the apparent quality of a water

FERMENTATION TUBE RESULTS POSITIVE TEST IN CUBIC CENTIMETERS			NUMBER OF B. COLI PER 100 CUBIC CENTIMETERS	
10	1.0	0.1	Phelps method	McCrady method
16/16	14/16		88.8	200
15/15	14/15		94.0	270
16/16	11/16		71.9	115
15/15	12/15		82.0	160
13/15	5/15		38.6	24
4/4	3/4		77.5	138
4/4	2/4		55.0	69
4/4	4/4	0/4	100.0	231
4/4	1/4	0/4	32.5	35
4/4	1/4	0/4	32.5	35
4/16	0/16		2.5	3
11/15	2/15		19.3	13
12/16	1/16		13.1	12
13/15	4/15		32.9	22
15/15	14/15		94.0	270
Average number per 100 cc.			55.6	106

NOTE. Above fermentation tube results taken from operating records (1917) of a filtration plant in Maryland. The results were obtained on the filter effluent before disinfection.

Past standards for B. coli content have shown a surprisingly patent disregard of the importance of stipulating the necessary frequency of sampling of a source before its quality may be safely postulated. *In fact no standard comes to mind at the present time in*

TABLE 6

Number of samples necessary to establish a B. coli content to within the probable errors of 5 and 10 per cent

(From Stein, *Engineering News Record,* May 24, 1917)

PER CENT OF POSITIVE TESTS IN A SERIES	NUMBER OF SAMPLES TO ESTABLISH B. COLI PER CUBIC CENTIMETER TO PROBABLE ERROR OF	
	± 10 per cent	± 5 per cent
5	1900	7600
10	900	3600
15	760	3040
20	627	2508
25	485	1940
30	365	1460
35	320	1280
30	282	968
45	235	940
50	204	816
55	190	760
60	171	684
65	165	660
70	162	648
75	155	620
80	156	624
85	160	640
90	178	712
95	210	840

which the number of samples is apparently considered of sufficient importance to warrant even a cursory establishment of a necessary minimum. In certifying a public water supply to common carriers how many state departments of health insist upon a large series of samples before passing judgment upon the analytical findings? Some of these collect samples two or three or four times a year and then certify or do not certify on the bacterial content of some 500 cc. of water out of a total consumption of millions of gallons per year. It is useless to justify such procedure upon the score that neither time nor finances are available to health officials to follow

adequately, by frequent sampling, the condition of the supply. Infrequency of sampling, with consequent inaccuracy of interpretation, is not always recognized by sanitarians as dangerous. It is for this blindness to the invalidity of findings based on essentially variable phenomena and methods that "standards" are in a measure directly responsible.

Stein[6] has pointed out within the last year the extreme importance of an adequate number of tests before any relatively precise conclusions may be projected. Table 6 contains a portion of the data developed by Stein to show the number of samples necessary to establish varying B. coli contents to within a 5 or 10 per cent probable error. In the Treasury Department standard an allowable maximum pollution equivalent to 20 per cent of all tests positive in 10 cc. is fixed. Twenty per cent was chosen, it may be inferred, in the belief that such a series of results would be comparable with a density of 2 B. coli per 100 cc. in the water. It is highly disconcerting to learn that, in order to obtain even a fair degree of precision and an approximate approach to the above number of B. coli, something like 600 samples are necessary. How meager, then, is the analytical information afforded by even 10 samples a year and how ludicrous is the certification of a doubtful supply upon the basis of only two examinations a year.

One's sense of scientific precision, and even of scientific attitude, suffers a jar when attempting to correlate the quality of a water with the data furnished in a number of other types of investigations. The pollution of streams, for instance, is studied by some governmental agency. Extensive reports are written, conclusions are drawn, correlations between the B. coli content of the stream and other sanitary features are made, and recommendations ensue. But even some of these apparently excellent researches become of little value or even misleading when the data upon which they rest have been scrutinized.

Is a pseudo-scientific correlation between B. coli content and dissolved oxygen in a stream of any importance when the number of B. coli in the stream at different stations, is obtained from one, two, or three fermentation tests? Yet table 7 is a partial list of the data culled from a recent federal report which will illustrate the derivation of unwarranted conclusions concerning the bacterial content of a stream, based upon a small number of analytical results. We must certainly question a B. coli content of 0.47 per cubic centimeter, when this quantitative index to the sanitary condition of the stream has

been obtained from only three samples. In a number of instances, too, the dilutions were not carried out far enough to give a negative fermentation test. The table loses further scientific interest when in another column the total count on agar at 37°C. is given, for a particular station, an average value of 90, a maximum of 90, and a minimum of 90, all derived from a *single* sample. It is extremely doubtful whether even a standard of utopian character would suffice to elimi-

TABLE 7

Frequency of sampling and the bacterial content of a stream at various stations
(From a recent federal report)

STREAM STATION	NUMBER OF SAMPLES	MEAN NUMBER OF B. COLI PER CUBIC CENTIMETER	TOTAL COUNT ON AGAR AT 37° C.		
			Average	High	Low
1	3	10.0	490	1160	40
2	3	46.8	630	1030	50
3	2	10.0	112	130	94
4	3	4.7	163	330	26
5	3	4.7	192	390	80
6	5	2.5	51	80	22
7	1	10.0	90	90	90
8	3	2.1	53	72	18
9	3	1.0	65	116	12
10	3	0.47	64	90	25
11	3	1.0	175	449	36
12	3	1.0	205	540	36
13	3	0.2	270	540	0

nate such data as the above. Further study of the significance of data, rather than their standardization, would be desirable. Such procedures would result, perhaps, in the abolition of haphazard stream study with bacteriological samples aggregating, at the most, five per station. It should be pointed out, too, that the above criticism is directed not so much at the failure to maintain frequent sampling, but rather at the intensive use of such data for study and for recommendation.

The method of making the B. coli examination of a single sample of water is capable of wide manipulation. The procedure in some laboratories usually consists in the inoculation of a series of fermentation tubes of different dilutions. The dilutions as a rule are in the usual geometric progression of 10, 1, 0.1, etc., cc. There does not

appear, however, to be any well-defined agreement among authorities as to the necessary number of fermentation tubes to be used at each dilution. The importance of using more than one tube at each dilution becomes manifest when it is borne in mind that Greenwood and Yule[4] have shown "that, if 'n' cc. have given a negative result, the chance of a second sample of 'n' cc. giving also a negative would be n/2n or 1/2." In other words, the chance of an inconsistency occurring when two tubes of the same dilution are used is no less than 1/2. It is clear, therefore, that too much emphasis cannot be placed upon the necessity of more than one tube at each dilution. It is of interest to note in this connection that some state department of health laboratories throughout the country recognize the value of numerous tubes, while others still use single tube determinations. Table 8 is a brief summary of the methods used in the laboratories and illustrates the wide possibility of interpretation of the quality of a supply, depending upon the laboratory in which the specimen happens to be examined. Certainly a sample of water examined in the laboratory of the State Department of Health of Connecticut may differ very materially in its supposed quality from a similar sample tested according to the methods in use in Michigan. It becomes extremely difficult, therefore, to compare types of water from different states upon the basis of percentage positive in different dilutions, when the details as to procedure are not given in complete form.

The effect of varying numbers of tubes can hardly be exaggerated, when the quality of a water is to be determined. Various refinements as to choice of numbers of tubes result very frequently in an improvement or degradation of the water in question, without any real difference in the colon content. A typical instance of such a procedure as the above is given by the method in use in a water filtration plant in Maryland. The laboratory at this plant determines the quality of its chlorinated filtered water by using a large number of fermentation tests in 10 cc., with a small number in 1 cc. In the month of June, 1917, for example, ten 10 cc., with only two or four 1 cc., samples were tested daily. The precision of results in 10 cc. was, therefore, something like twice that of the findings in 1 cc., since it varies as the square root of the number of samples. Such a system resulted in an unconscious placing of a premium on not finding B. coli in the lower dilution. Inasmuch as the quality of the chlorinated effluent, in this particular instance, was none too good, as indicated by the presumptive tests, it was distinctly advantageous, for a better

TABLE 8

Comparison of number of tubes used at each dilution in routine fermentation tests for B. coli in state department of health laboratories

NAME OF STATE	NUMBER OF TUBES USED IN DILUTION OF				
	10 cc.	5 cc.	1 cc.	0.1 cc.	0.01 cc.
California	2		2	2	
Connecticut	1		1	1	
District of Columbia	1	1	1	1	1
Florida	2		2	2	
Georgia	5		1		
Illinois	2		2	2	
Indiana	1		1	1	
Iowa	1 to 5		1 to 2		
Kentucky	1 to 5		1 to 5	1 to 5	
Maine	2		5		
Maryland	5		1 to 5	1	1
Massachusetts	1		1	1	
Michigan	7		7	7	
Missouri		1	5	3	
Montana			3 (2cc.)		
New Hampshire	3 to 5		1		
New Jersey					
Public supplies			5		
Private and new supplies			5	5	
Raw—highly polluted			2	2	2
New York	3		3	3	
North Carolina	1		1	1	
Ohio	1		2		
Rhode Island	1 to 2		1 to 2	1 to 2	
South Carolina	2		2	2	
South Dakota	3				
Vermont			1		
West Virginia	2		1		
Wyoming	2		2	2	

NOTE. See note in table 1.

showing of the plant, that the number of tubes should be reduced in the lower dilution. This was done, whether consciously or unconsciously is unimportant, with the consequence that during the month 232 tubes were used in the 10 cc. tests, while only 94 were employed in the 1 cc., or a ratio of precision in the two instances of approximately 1.6 to 1.0. The intensity of search for B. coli in the 1.0 cc. dilutions (the more important of the two under discussion) was therefore

materially reduced and the corresponding quality of the water probably enhanced. This was undoubtedly the case, since the proportion of positive tests in the 10 cc. was high (74 per cent) while in the 1 cc. it was only 7.4 per cent. It is somewhat hard to believe the data of a certain day when ten 10 cc. tubes were all found to be positive, while all of the four 1 cc. tests were negative. Here evidently the relative reduction of the number of tubes in 1 cc. from that in 10 cc. has created a less inferior quality of effluent to that probably existing. That the above conclusion is justified is inherent in the fact that, given a necessary predominance of possible negative over positive tests, or a low initial density of bacilli relative to the particular dilution, the smaller the number of total examinations the better the apparent quality of the water. In a small total number of tubes, the probability of the few possible positive tests appearing becomes very slight.

Chemical determinations. The importance of chemical examinations in determining the quality of a supply has been given considerable discussion in past years. The necessity for the so-called sanitary determinations has ranged from the viewpoint of the advocate of continuous and complete chemical analyses, as in Massachusetts, to the more radical exponents of the complete omission of sanitary chemical tests, as, for instance, the public health officials of Minnesota. The establishment of chemical standards for quality of water need not be gone into here in any detail, since both the methods and the accuracy of results in this field of water analysis are far more advanced than in the case of the bacterial tests. The problem in this instance, however, as well as in the case of bacterial standards, seems to lie more in the further study of the relative significance of data rather than in the establishment of meaningless standards based upon incomplete and variable manifestations of hidden phenomena.

Sanitary survey. Although the sanitary survey, or the study of the natural physical features surrounding a given water supply, has always been recognized as of prime importance in the consideration of the safety of a water, yet it has been rarely given the emphasis it necessarily demands in the establishment of arbitrary standards. It has been only recently that the United States Treasury Department has stipulated in its requirements that a sanitary survey of the sources of a supply should be included in the summary of the condition or quality of the water to be certified. Just what relative weight the field survey, as opposed to the bacteriological analysis, is given in the above system of standardization it is not possible to state. Pre-

cedent, too, has given far more consideration to the question of bacterial content than to any other extraneous features, with the result that, if the survey proves unsatisfactory, the layman and often the health officer of questionable honesty lay stress upon the more elusive and shadowy bacterial content. If a field survey indicates, for instance, that a water is subjected to filtration and disinfection under the guidance of the town plumber, with its attendant inconsistency of performance and continual hazard of unsuccessful purification, should or would such a survey preclude the issuance of a certificate, if the analytical data resulting from a few choice samples collected by the town authorities show the water to meet the "1/5 in 10 cc." requirement? It would seem that the artificial standard often serves the purpose of indicating the loophole through which the inefficient water company may escape, rather than of clarifying the situation as to doubtful quality.

That the general field survey has been given in the past by some sanitarians the attention it requires is undoubtedly true. Whittaker,[8] for instance, has pointed out within the last few months, as a result of a number of years of experience in Minnesota, that "the field survey and analytical results together should afford information on which recommendations can be made for the protection or abandonment of the supply." The standards of quality of water supplies should include, therefore, not only recommendations as to analytical data, but injunctions as to field or sanitary surveys. The establishment of standards as to "structural, environmental and operative features" would require,[8] in a greater degree even than similar attempts as to analytical work, an immediate standardization of method of survey rather than an evaluation of the results or findings of the survey. Here, as in the case of other possible quantitative water standards, the necessity indicates that the units of measure must be devised before the limitations of such units, as yet non-existent, may be determined. It is the latter feature of the above axiomatic statement upon which most advocates of standards of quality lay particular stress.

PRESENT STANDARDS OF QUALITY OF WATER

State departments of health. The attitude of official sanitarians, such as those in charge of the activities of the various state depart-

[8] H. A. Whittaker, Fallacies in the Investigation of Water Supplies. *Jour. A. P. H. A.*, Vol. VII, No. 9.

ments of health, toward the advisability or necessity of the use or adoption of arbitrary standards of quality is reflected somewhat in the fact that Connecticut, Florida, Illinois, Indiana, Iowa, Kansas, Kentucky, Maine, Maryland, Massachusetts, Minnesota, Missouri, Montana, New Hampshire, New Jersey, New York, North Carolina, Rhode Island, South Carolina, South Dakota, Virginia and Wyoming use no arbitrary standard for interpretation, while California, Georgia, Michigan and Wisconsin use the United States Treasury Department standard or some variation thereof at some or all times. A number of the analysts and sanitary engineers expressed the opinion rather vehemently that no general standard could be devised to fit the peculiar conditions existing in that particular section of the country. Stephen De M. Gage, Chief of the Division of Chemistry and Sanitary Engineering of the Rhode Island State Board of Health, expresses[9] the situation with clarity in the following terms:

> We do not use any arbitrary standard of quality of water. Each individual sample is judged upon its own merits, as shown not only by the bacterial examination but by result of the chemical tests and general knowledge of sanitary surroundings by inspection of the source. It is not practicable nor fair to attempt to apply any arbitrary standard of quality, bacterial or chemical, to New England waters.

It is interesting to note in all the correspondence with the various state departments of health that the United States Treasury standard is used in practically every instance in the certification of railroad water supplies, but in only 4 of the 24 is it applied generally to others. Opinions vary widely as to the desirability of adhering strictly to the bacterial limits given in the above standard. Frank Bachman, of the California State Board of Health, states[10] that

> The Treasury Department's standards are too severe for municipal water supplies and that the 1 cc. standard used a few years ago was too low. Our arbitrary standard is between the two.

Edmon Greenfield, of the Illinois State Water Survey, agrees[11] somewhat with the above in expressing the opinion that

> In many cases we consider the standards proposed by the United States Treasury Department for water to be used on interstate carriers as just and

---

[9] Stephen De M. Gage, By letter, dated November 21, 1917.
[10] Frank Bachman, By letter, dated December 3, 1917.
[11] Edmon Greenfield, By letter, dated November 13, 1917.

satisfactory. In other cases we do not feel that they apply as well as they might. The standard suggested by the United States Treasury Department for total count on agar at $37\frac{1}{2}°$ seems to be quite lenient, while the standard for minimum content of B. coli seems to be quite severe in some cases.

In Virginia, on the other hand, Dr. Fitzgerald, bacteriologist for the State Board of Health, assumes[12] a different attitude by pointing out that

Our standards of quality vary from those of the Public Health Service, since we allow in certain samples a count of under 500. We classify samples showing colon bacilli in 1 cc. "bad," 10 cc. and 20 cc. "suspicious."

Bearing in mind the fact that the methods of arriving at bacterial results differ widely in the various laboratories and that the arbitrary standards, wherever they exist, are interpreted with considerable differences of opinion, we should not be very far astray in concluding that "standards of quality" are not entirely favorably viewed by most of the official sanitarians. That new and impracticable standards are not only undesirable, but almost impossible of establishment at this time, also seems to be the consensus of opinion of a large part of the analysts and sanitary engineers.

United States Treasury Department standard. The power of conjuring with the name of the federal government often leads to the adoption of procedures which, under unofficial stamp, would be subjected to closer scrutiny and to more suspicion. The bare requirements of the United States Treasury Department Standard have been accepted by many as a convenient, automatic, and almost mathematical means of determining the safety of an unknown supply. Given certain known quantities of water, a few bacteriological tests, the substitution of results in an equation, and the problem was solved. The standard is apparently definite, precise, and easy of application, but does it given an accurate index to the quality of a water supply? As usually carried out, the standard undoubtedly does not. It does not perform its function as quickly, as safely, as exactly as, even today, many health officials assume.

The federal requirements stipulate that

The total number of bacteria developing on standard agar plates, incubated twenty-four hours at 37°C., shall not exceed 100 per cubic centimeter. Provided, that the estimate shall be made from not less than two plates, showing such numbers and distribution of colonies as to indicate that the estimate is reliable and accurate.

[12] Jas. O. Fitzgerald, By letter, dated November 13, 1917.

How reliable and accurate such estimates may be is made clear by the following abstracts from a discussion[13] by Prof. Geo. C. Whipple on "The Element of Chance in Sanitation."

The chance of a single bacteriological count exceeding a given standard of 100 when the actual number present in the sample is the figure given in the first column:

NUMBER OF BACTERIA PRESENT	CHANCE OF A SINGLE SAMPLE EXCEEDING THE STANDARD OF 100
100	1 in 2
90	1 in 2.8
80	1 in 5
70	1 in 12.5
60	1 in 66.6
50	1 in 2500

On the other hand, in a sample of water which contained more bacteria than the standard, there would have been a chance that the plate contained fewer bacteria than the standard.

NUMBER OF BACTERIA PRESENT	CHANCE OF A SINGLE SAMPLE BEING LESS THAN THE STANDARD OF 100
100	1 in 2
110	1 in 2.6
120	1 in 3.4
130	1 in 4.5
140	1 in 6.1
150	1 in 7.7
200	1 in 20.0

It will be seen from these figures that in the case of waters which contain fewer bacteria than the standard, but near it, the chance of a single count exceeding the standard is high but in samples which contain much fewer numbers than the standard the chance of a single count exceeding the standard decreases rapidly. In the case of samples which contain more bacteria than the standard the chance of a single count showing less than the standard is considerable. The chance of a bad sample being called good is greater than the chance of a good sample being called bad if the number of bacteria present differs greatly from the standard.

It is evident that when dependence is placed upon a single bacterial count a rigid application of the standard is likely to do injustice either on one side

[13] G. C. Whipple, The Element of Chance in Sanitation. *Jour. Franklin Institute*, August, 1916.

or the other. It is evident, therefore, that in order to prevent injustice being done in the application of quantitative bacteriological standards to water it is necessary that several tests should be made. The number of plates which should be made in any given case has not been definitely determined, but, obviously, a large number of plates should be made whenever there is reason to suspect that the water approaches a given standard in its bacterial content. For waters which are expected to be below the standard two plates would probably be sufficient, but under many conditions five or even ten plates may be necessary to give results which can be safely depended upon.

Since the number of samples and of plates vary considerably in different applications of the United States Treasury standard, it is entirely problematical what the significance of an allowable count of 100 is when the count may be obtained through the medium of one sample or several hundred during the year.

The second criterion of the federal requirement that "not more than one out of five 10 cc. portions of any sample examined shall show the presence of organisms of the B. coli group" leads one into further complications, when it is kept in mind that it was the intent of the standard to allow a possible maximum B. coli content of only 2 per 100 cc. The 1/5 in 10 cc. requirement was assumed to give a convenient method of testing the allowable "2 per 100 cc." content. How successfully it may succeed in doing this may be gathered from the following discussion[5] by McCrady.

Some calculations indicating the percentage of various results which will occur when various numbers of B. coli are contained in the sample, are shown below.

NUMBER OF B. COLI IN SAMPLE X	PERCENTAGE OF TIME THAT "0/5 IN 10 CC." WILL OCCUR	PERCENTAGE OF TIME THAT "1/5 IN 10 CC." WILL OCCUR	PERCENTAGE OF TIME THAT "2/5 IN 10 CC." WILL OCCUR
0	100.0	0	0
1	50.0	50.0	0
2	25.0	55.0	20
3	12.5	45.0	36
4	6.25	33.55	
5	3.13	23.26	
6	1.56	15.52	
7	0.78	10.09	
8	0.39	6.44	
9	0.19	4.05	
10		2.54	
11		1.57	

It will be noticed from these calculations that when 4 B. coli are present in the sample, the sample will pass the standard about 40 per cent of the time. And one out of about every six samples, containing 6 B. coli, will pass the standard (1.56 per cent plus 15.52 per cent). On the other hand, one out of every five samples containing only 2 B. coli per 100 cc. will fail to pass the standard.

Consequently, when it is remembered that the standard signifies a most probable limit of 2 B. coli per 100 cc., it is evident that the standard method of analysis renders the standard much more lenient than might, at first glance, be supposed.

The above discussions illustrate the possible defects of the Treasury Department standard when the requirements are literally followed. Since no complete directions are given as to method, frequency of sampling, or interpretation of the analytical procedures outlined, the possible variations in significance of the standard become manifest. The standard becomes, therefore, not a precise and accurate index as to quality, but rather simply a convenient mode of analysis to be used with considerable caution for comparative purposes.

A rather curious abuse of the federal standard has resulted in recent years from the failure of the requirement to specify the exact and relative importance of the somewhat "delphic utterance" that "it is recommended, as a routine procedure, that in addition to five 10 cc. portions, one 1 cc. portion, and one 0.1 cc. portion of each sample examined be planted in a lactose peptone broth fermentation tube, in order to demonstrate more fully the extent of pollution in grossly polluted samples." Inasmuch as the requirements suggest the 1 and 0.1 cc. tests, but make no stipulation as to their relative significance, it becomes extremely convenient for health authorities, water companies and filtration plant operators to discard the lower dilutions whenever the results in 10 cc. meet their purposes better. It should be borne in mind that unfortunately the aim of some who operate water supplies is not always to determine the real quality of the supply, but to defend it, in the face of criticism, by endeavoring to show, through judicious selection of data, that the water passes the standard of the United States Treasury Department.

A striking illustration of such a procedure is given by the situation in one of the cities in Maryland. The municipal supply is not always of the best and controversial discussion as to quality has occurred from time to time between state and municipal health authorities. The question of certifying to the supply is still a source of disagreement, simply because of the vagueness of the federal requirements.

A municipal official may insist upon the selection of a short series of good results that may have occurred just prior to the date for certification, when these results are not typical of those obtained during the rest of the year, or upon the strict application of the 10 cc. criterion, in the face of contradictory evidence given by lower dilutions. A discussion of the data shown in table 9 will make the situation clearer. In this table there have been collected the results of laboratory examinations extending over the year 1917. By averaging only the 10 cc. results for the year and estimating from these the number of B. coli per 100 cc. (by Phelps' method), we obtain an average B. coli content of 2.43 per 100 cc. This value is somewhere near the maximum allowable density usually assumed as the requirement of the Treasury Department. When using the additional results of 1 and 0.1 cc. dilutions, the quality of the water takes on an entirely different aspect. The average number of B. coli per 100 cc. (also calculated by Phelps' method) now becomes 24.62, or over ten times

TABLE 9

Significance of 1.0 and 0.1 cc. dilutions in determining the quality of a supply by the United States Treasury Department standard

1917 MONTH	B. COLI PER CENT POSITIVE CONFIRMED IN			B. COLI PER 100 CC. (BY PHELPS' METHOD)
	10 cc.	1 cc.	0.1 cc.	
January	20.5	6.4	0.6	13.21
February	61.9	26.5	6.2	
March	26.3	9.0	3.2	39.53
April	16.7	3.6	1.4	17.51
May	26.7	9.3	0.7	17.34
June	33.3	15.1	2.4	38.52
July	26.8	15.7	6.3	73.51
August	26.0	12.0	2.0	31.40
September	39.0	10.0	1.0	21.90
October	18.0	2.1	0.0	3.69
November	24.3	0.0	0.9	11.43
December	9.9	2.0	0.0	2.79

Average B. coli index, from 10 cc. results only = 2.43 per 100 cc. (exclusive of February).

Average B. coli index from 10, 1 and 0.1 cc. dilutions = 24.62 per 100 cc. (exclusive of February).

NOTE. Above results obtained from tap water analyses in city in Maryland. Average number of samples approximately 125 per month.

the value obtained from the 10 cc. dilutions alone. The city health official would support his contention as to certifiability upon the 10 cc. basis while ignoring the much less attractive 1 and 0.1 cc. results.

In the month of April, for instance, the water, on the basis of the 10 cc. figure, would meet the certification requirement. Yet, by using all the data available, the B. coli content of the water may be assumed to be 17.51 per 100 cc. If the 1 and 0.1 cc. dilutions had not been made, as is often the case, the doubt as to the superior quality of the supply would have been removed, in spite of the fact that the water contained approximately nine times as many B. coli as is tacitly allowed by the federal requirements.

The above data and their application are not at all hypothetical, but are exact and accurate duplicates of conditions which have occurred in Maryland, and probably in other states, as a result of the compulsory adoption of exact standards and their adaptation to variable phenomena. In such instances, the application of the standard aids the official to dodge the responsibility of producing water of excellent quality, instead of serving as the means of detecting poor quality.

It is well to point out, before leaving the discussion on the federal standard, that, if any changes are contemplated in its requirements, emphasis must be placed upon the necessity of using all the data extending over the periods intermediate between the official certification dates, rather than a few choice samples collected just prior thereto. Too often a large series of earlier results are discarded for more convenient later data. It comes about, therefore, that the present federal requirement may assume a two-fold aspect depending upon the whim of the water supply administrator. Incidentally, haphazard certification to the Treasury Department by local health officials, who are frequently over-zealous, should be stopped and this duty delegated only to the state health organizations.

Filtration plants. The analytical methods in use at the various filtration plants throughout the country have been made the subject of an extensive and detailed compilation within recent months by Jack J. Hinman, Jr., of the Iowa State Board of Health. Mr. Hinman has gathered such complete data on this subject that it would be entirely unnecessary to discuss here the procedures further than to quote from one of his discussions[14] the following words:

[14] J. J. Hinman, Jr., Water Works Laboratories. *Iowa Academy of Science*, Vol. xxiv, 1917.

A glance at the table will show you that in spite of the excellent work which has been done in the preparation of our Standard Methods of Water Analysis, the bacteriological procedure of the water plants is far from uniform.

It seems, therefore, that the possibilities of obtaining definite units of measure of quality for filter plant effluents are as remote as those for general water supplies.

It is of passing interest to note at this point several deleterious effects of the past standardization of filter effluents upon an accurate interpretation of quality. One of the oldest methods of rating filtration plant performance, in reality sometimes resulting only in a specious attempt to conceal by circuitous methods the quality of an effluent, is the familiar "percentage efficiency" method. Its basis, its shortcomings, its dangers, even today, have been elaborated time and again, but the "percentage efficiency" still persists as the old "war horse" blinder for inefficiency and poor effluent.

Attention is called here only briefly to another practice which has come to the author's attention in the use of the above method, resulting in an added objection to the formation of reckless standards which years do not serve to obliterate from the minds of the gullible public. The average percentage removal of bacteria during a particular month means to most laymen the usual or mean removal effected during individual days. If this average figure happens to reach 98, then all is well in the heart of the consumer, if not in the mind of the health officer. If this method of standardization is to be used, its mathematical evaluation should be, at least, properly developed. Strange as it may seem, the practice has persisted in two of the filtration plants in Maryland of summing up the total raw water and effluent bacteria for the month and calculating from these totals the average monthly percentage removal. This resulted, for example, for one step of the purification process, in a figure of 77.0 during a month in which more than 40 per cent of the days show a percentage removal of 47 or under, while at no time during the month did the removal exceed 93 per cent.

The obvious effect of calculating average percentage removals by means of total bacteria for the month is to vitiate the poor results of many days by good results on a few. The ordinary and real operating results of the plant are totally lost sight of. This effect is made clear by the following series of results from the plant under discussion

June 18–23, bacterial removal, coagulating basins to filter effluent

DAY OF MONTH	AVERAGE COUNT, 20°C.		PER CENT REMOVAL
	Coagulating basin effluent	Filter effluent (Unchlorinated)	
June 18	1355	160	88
June 19	295	210	29
June 20	135	85	37
June 21	1280	146	89
June 22	130	124	5
June 23	285	180	37
Totals	3480	905	285

Average percentage removal—by Method (a), 74.0
by Method (b), 47.5

The percentage removal designated (a) is the value obtained by the method in use at the plant, consisting of the percentage change in the total numbers of bacteria for the week. This value is recorded, then, as the average percentage removal, in spite of the fact that on four days out of the six the performance was nowhere near 74.0 per cent. It is manifest from the above data that two excessively high basin counts hide completely, in method (a), the poor results obtained during two-thirds of the week. The undue influence of a few high raw water counts is accentuated, due to the fact that they are almost always accompanied by high percentage removals (for instance, June 18 and 21). A few days, or even one day, of high raw water counts may predetermine the value of the percentage removal for a whole month. Table 10 is exhibited in this connection, since it illustrates the possibilities of statistical juggling even with such an apparently stable and uniform procedure as the calculation of percentage removal. In explanation, it should be pointed out that method (b) consisted of obtaining the average of the *daily percentage removals* (as stipulated in the report of the committee of the New England Water Works Association, January 13, 1915) rather than the percentage removal of the total raw water and effluent bacteria. In a discussion of the average performance of a plant, the individual daily performances are dealt with, since the *performance*, not the bacteria, is under scrutiny.

The above discussion illustrates the abuses to which a standard or unit of measure may be subjected when the mode of determining

the unit has not been defined in iron-clad terms; and, secondly, it illustrates a fallacy which has not always been kept clearly before us, that is, that a measure of performance, whatever its method of calculation, is not synonymous with a measure of the quality of an effluent. It may frequently happen that the unit of performance may be so chosen as to give an index to the quality of the effluent, but the same objections cannot be raised to standards of performance as to those of quality. In the former, comparative data may always be used in the study of the functioning of a plant, regardless

TABLE 10

Comparison between average percentage removals obtained by two different methods of calculation

MONTH		PERCENTAGE REMOVAL						
		Turbidity			Bacteria at 20° C.			
		Basin 1	Basin 2	Filters	Basin 1	Basin 2	Filters	Chlorine
January	Reported	73.5	76.0	94.5	75.0	77.0	94.5	93.0
	Revised	50.0	53.0	95.5	53.0	48.0	93.8	90.5
March	Reported	89.5	90.5	96.7	86.0	87.0	75.0	97.0
	Revised	77.2	80.4	97.7	80.0	83.0	71.7	95.6
April	Reported	79.0	79.0	100.0	84.5	82.5	88.5	91.0
	Revised	76.2	77.1	100.0	78.0	71.2	88.8	73.3
May	Reported	78.0	79.0	100.0	71.0	61.0	66.0	92.0
	Revised	76.3	77.4	100.0	70.0	53.0	57.0	66.0
June	Reported	87.0	98.0	98.5	88.0	86.0	80.0	71.0
	Revised	76.0	78.1	98.1	74.7	73.0	67.8	63.2
July	Reported	89.0	92.0	100.0	84.0	82.0	69.0	78.0
	Revised	77.9	81.7	99.3	64.0	60.9	64.0	52.0
August	Reported	71.0	73.0	96.0	59.0	37.0	62.0	93.0
	Revised	69.4	67.3	97.3	42.3	21.0	54.5	86.5

NOTE. *Reported* results calculated by Method (a)—see text.

Revised results calculated by Method (b)—see text.

Reported results taken from records of a filtration plant in Maryland. The percentages are calculated for successive steps of the purification process.

of their peculiar significance, but in the latter, the significance of absolute, and not relative, values is to be considered.

SUMMARY

The establishment of a standard of quality for potable water means the setting up by some accepted authority of a rule for the measure of quality. Since quality is a variable attribute, intricately dependent upon a series of natural physical, chemical and biological phenomena, its measurement becomes extremely difficult. The quality of a particular water cannot, in most instances, be measured adequately by means of the evaluation of only one of its characteristics. The real consideration or interpretation of the potability of a supply involves a series of mutually active attributes, each of which plays a part of importance in modifying and determining the character of the water. Any scientific and practical standard must include, therefore, a composite of all those features which influence a change in quality. The single ultimate unit of measure or the final standard becomes, in this way, an index number of properly weighted individual and fundamental units.

The prime requisites for the establishment of any standard are the existence of those basic units which are to be its components and of universal agreement as to the relative significance of such components. In the field of water supply neither of the two above requirements has been fully met. Basic or fundamental units for measurement of quality have not been established with any degree of exactness or accuracy. A unit of measure, such as the B. coli content, certainly cannot be predicated upon such variable procedures as are now followed, without resulting in a confusion of interpretation. The establishment of any unit demands an absolute consistency in its measurement. It is this consistency of measurement which is now absent in practically every available measure of quality.

If inconsistency reigns in the determination of the fundamental units, such as the total count, the B. coli content, the chemical constituents and the sanitary survey, then the general standard of quality, a derived unit composed of basic measures, becomes of extremely little value. If we add to this consideration of inconsistent method of obtaining individual units the fact that their relative significance is still unsettled, then a general standard becomes practically useless and even misleading.

From the above discussion, it becomes clear that the study of the *method* of evaluating a unit must of necessity antedate the attempt to establish *limiting values* of such a unit. A critical survey of past standards of quality seems to indicate an assumption that the method of unit-evaluation is fixed, and therefore that limiting values are the desiderata. It is not felt that the status of laboratory or field method of analytical examination warrants any such assumption. The field for future standardization of quality of water supplies would appear to lie more immediately in the consideration of such problems as the relative significance of different bacterial counts, the methods of obtaining the counts, the necessary frequency of sampling, of plating, of numbers of fermentation tubes, the numerical interpretation of usual fermentation tube results, the allowable variations from specified bacterial contents, the determination of real bacterial indices to sewage pollution, the importance of chemical determinations, and the standardization of field survey method. More remotely, the problem of standards is concerned with the coördination of the results of such studies as the above in such a way as to construct a composite unit of measure. Until these studies have been made and a general agreement reached, a standard would have but little value.